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Heat Stress in Broiler Chickens.

by J Cochrane.

Summary

A simple model of heat and moisture exchange is constructed for 6 to 8 week old broiler chickens. The model is used to estimate environment temperatures which the bird can tolerate and compares these with air temperatures experienced during the recent incidents of bird deaths due to heat stress.

Introduction

In most summers, a number of broiler chickens die - apparently from heat stress - during hot spells. These incidents are more numerous and serious in summers such as 1976 and 1983 when daytime temperatures rise towards 30°C. In one incident in 1983, for example, almost 18,500 birds died on one farm during a 10-day period in which 14,700 (10.5% of the flock) died in one day.

A Meteorological Office warning scheme exists to give advice of likely occurrence of 4 or more hours with temperatures above 23°C. The purpose of this study is to determine the temperature at which protective measures should be initiated and to see whether a simple model might give some indication of the type of action which would help to alleviate heat stress.

The Model and Basic Assumptions

1. Broiler stocks, growing at about 40g d^{-1}, from 1.5kg at 6 weeks to 2.0kg at 8 weeks old, are considered.

2. Total heat output for such birds, at temperatures between 20 and 30°C, is 10 and 12.5 W $bird^{-1}$ respectively ie the 1.5kg bird produces 10J s^{-1} and the 2.0kg bird 12.5J s^{-1}. (Ref 1)

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3. Evaporative moisture output. In Ref 2 we find a suggested normal usage of 75g d^{-1} for a 2.0kg bird at 20°C with an extreme rate of 340g d^{-1} for a 1.5kg bird at 29°C.

Ota (Ref 4) gives data for 1.8kg White Leghorn and 2.5kg Rhode Island laying birds which suggest a respired water use of about 120g d^{-1} at 20°C rising to about 200g d^{-1} at 35°C.

The ability of the bird to use evaporative processes to dissipate body heat is limited by i) the difference in moisture holding capacity of inhaled and exhaled air and ii) the quantity of air which the bird can pass through its respiratory system in a given time.

The moisture content of the air can be estimated from:-

$$d = 217\ e / T$$

where

d = absolute humidity (g m^{-3})

e = vapour pressure (mbar)

T = temperature (K)

Assuming that the air can change from ambient temperature and relative humidity to body temperature and 95% relative humidity while passing through the respiratory tract, we can estimate the quantity of water removed:-

Temperature		RH	Vapour Pressure	Humidity
Air	Body			
°C		%	mbar.	g m^{-3}
21		50	12.5	9.2
25		50	16	11.6
	41	95	73	50.5
	44	95	86	58.9
	46	95	96	65.3

In order to estimate water use by the bird we need to know the volume of air which passes through the system.

Sturkie (Ref 3, in Table 31) quotes Weiss et al to show minute volume of respiration of chickens ranging from 554 ml for a normal bird at body

temperature of 41.4°C, through 926ml for a hyperthermic bird at 42 to 43°C to 1565ml for a hyperthermic bird at 44 to 45.5°C.

At these rates of respiration the normal bird inhaling air at 21°C, 50% RH and exhaling air at 40°C, 95% RH will use (50.5 - 9.2) x 0.000554g min^{-1} or 33g d^{-1} - less than half the value suggested above as normal.

Similarly, the hyperthermic bird at body temperature of around 44°C inhaling air at 25°C, 50% RH will be using only about 100g d^{-1}.

Sturkie (op. cit., Figure 29) shows minute volume increasing from 750ml at normal body temperatures to about 2250ml for a hyperthermic bird at body temperatures between 44 and 46°C. These respiration rates would allow for evaporative water use of about 45g d^{-1} at normal body temperatures rising to about 150g d^{-1} for a bird under stress. The bird's respiration rate would have to be more than doubled to attain the rate of water use of 340g d^{-1} previously suggested. Nevertheless, for the larger broiler bird, such a rate might be sustained for a limited period.

For the purpose of this study, it will be assumed that the bird will use water for evaporative cooling at rates between 50 and 150g d^{-1} in normal summer conditions; evaporative water use may rise to rates equivalent to 200 to 350g d^{-1}, for short periods, in response to increasing hyperthermia.

4. Stocking density is 20 birds m^{-2}

5. The problem now arises - "How big is a chicken?"
Consider the 2.0kg bird as having a body equivalent to a sphere of 20cm diameter. Its volume will be 4190cm^3 and its surface area 1260cm^2. Each wing is considered to have an area of (20 x 10)cm^2 effective in heat exchange processes.
The effective surface area is:-

1260cm^2 (body) + (4 x 20 x 10)cm^2 (wings).

Assuming that the "density" of the 1.5kg bird is the same as that of the larger - 2.1g cm^{-3} - the 1.5kg bird will have a diameter of 18cm and a body surface area of 1020cm^2; the effective wing area is assumed to be the same as for the larger bird.
Average thickness of feathers is taken as 1.0cm over the body and 0.5cm on the wings. This gives an overall figure for the birds of:-

2060cm^2 x 0.8cm at 2.0kg

1820cm^2 x 0.8cm at 1.5kg

6. Evaporative heat loss is calculated from:-

$$E = LE \times W / 24 \times 3600$$

where

E = evaporative cooling ($J\ s^{-1}$)

LE = latent heat of water - taken as 580cal g^{-1}, equivalent to 2428J g^{-1}.

W = water use ($g\ d^{-1}\ bird^{-1}$)

Water use $g\ d^{-1} bird^{-1}$	Evaporative cooling $J\ s^{-1}$
50	1.4
75	2.1
100	2.8
150	4.2
200	5.6
250	7.0
300	8.4
350	9.8

7. Flow of sensible heat to the surrounding air can be described by:-

$$H_S = TC \times (T_b - T_e) \times A / X \ J\ s^{-1}$$

where

H_S = sensible heat transfer ($J\ s^{-1}\ bird^{-1}$)

TC = apparent thermal conductivity of feathers - taken as 0.000057cal $cm^{-1}\ s^{-1}\ K^{-1}$, equivalent to 0.0002386J $cm^{-1}\ s^{-1}\ K^{-1}$ (Ref 4)

T_b = body temperature (^{o}C)

T_e = environment temperature (^{o}C)

A = surface area (cm^2)

X = thickness of feather layer (cm)

Solving the above expression for T_e will give the environment temperature at which sensible heat production and transfer are in balance and body temperature may be maintained. If heat production exceeds the rate at which heat can be dissipated to the surroundings, then body temperature must start to rise and heat stress increase.

The expression for environment temperature becomes:-

$$T_e = T_b - (H_s \times X) / (TC \times A)$$

Results of model calculations

1. Assume that we wish to keep the bird's body temperature constant at 41°C and that the lower (sustainable) rates of water use are applicable. Tolerable environment temperatures in the house, T_e, at different rates of water use are:-

Weight:		1.5kg		2.0kg	
Water use	E	H_s	T_e	H_s	T_e
g d^{-1}	J s^{-1}	J s^{-1}	°C	J s^{-1}	°C
50	1.4	8.6	25.2	11.1	22.9
75	2.1	7.9	26.4	10.4	24.1
100	2.8	7.2	27.7	9.7	25.2
150	4.2	5.8	30.3	8.3	27.5

These figures assume that the whole of the bird's surface area is exposed to ventilating air and is effective in heat dissipation.

2. If, due to crowding or clustering, the bird's effective surface area is reduced by say 25% or 50%, the tolerance temperatures at which body temperature can be maintained become:-

Weight:	1.5kg		2.0kg	
Water Use	0.75A	0.5A	0.75A	0.5A
		T_e		
50	19.9	9.3	16.9	4.9
75	21.6	11.9	18.4	7.1
100	23.3	14.5	19.9	9.4
150	26.7	19.6	23.0	14.0

Under conditions of local overcrowding, the birds cannot maintain its body temperature - even at high rate of water use - at house temperatures as low as 15 to 20°C.

If we regard heat stress as beginning at the temperature at which the bird can no longer maintain normal body temperature, a threshold environment temperature of between 25 and 30°C would seem to be an acceptable figure - with the possibility of some localised stress at temperatures as low as 20°C.

3. If body temperature can rise, under increasing stress, to 45 - 46°C before death occurs, then the tolerance temperatures above may be raised by up to 5°C.

If at the same time we allow water use to increase we can estimate environment temperatures which may be tolerated for shorter periods.

Weight:			1.5kg					
Body temperature:			43°C			45°C		
W	E	H_s	1.0A	0.75A	0.5A	1.0A	0.75A	0.5A
					T_e			
200	5.6	4.4	35	32	27	37	34	29
250	7.0	3.0	38	36	32	40	38	34
300	8.4	1.6	40	39	37	42	41	39
350	9.8	0.2	43	43	42	45	45	44
					2.0kg			
200	5.6	6.9	32	28	20	34	30	22
250	7.0	5.5	34	31	25	36	33	27
300	8.4	4.1	36	34	30	38	36	32
350	9.8	2.7	39	37	34	41	39	36

4. Effects of varying the house ventilation rate.

The recommended maximum ventilation rate is 28m³ s^{-1} per 10,000 birds.

The house temperature may be estimated from:-

$$T_r = H_s / (1200 \times Q + U \times A') \qquad \text{(Ref 5)}$$

where

T_r = temperature rise over outside air (°C)

H_s = sensible heat output (W $bird^{-1}$)

Q = ventilation rate (m^3 s^{-1} $bird^{-1}$)

U = average thermal conductance of roof and walls - here taken to be 0.5W m^{-2} K^{-1}.

A' = exposed area of roof and walls per bird - normally 1.5 / stocking density (m^2 $bird^{-1}$)

The data presented in paras 2 and 3 above can be modified to allow for the rise of house over ambient air temperature at different rates of (house) ventilation.

At maximum ventilation rate we have:-

		Weight:	1.5kg					
		Body temperature:	43°C			45°C		
W	E	H_s	1.0A	0.75A	0.5A	1.0A	0.75A	0.5A
			T_a					
150	4.2	5.8	30	27	20	32	29	22
200	5.6	4.4	34	31	26	36	33	28
250	7.0	3.0	37	35	31	39	37	33
300	8.4	1.6	40	39	37	42	41	39
350	9.8	0.2	43	43	42	45	45	44
		Weight:	2.0kg					
150	4.2	8.3	27	23	14	29	25	16
200	5.6	6.9	30	26	18	32	28	20
250	7.0	5.5	32	29	23	34	31	25
300	8.4	4.1	35	33	29	37	34	31
350	9.8	2.7	38	36	33	40	38	35

If, because of clustering or other reasons, effective ventilation is reduced by 50%, these tolerance air temperatures become:-

			1.5kg				
150	29	26	19	31	28	20	
200	32	29	24	34	31	26	
250	36	34	30	38	36	32	
300	39	38	36	41	40	38	
350	43	43	42	45	45	44	
			2.0kg				
150	25	21	12	27	23	14	
200	28	24	16	30	26	18	
250	31	28	22	33	30	24	
300	34	32	28	36	34	30	
350	37	35	32	39	37	34	

Discussion

1. The residual values of H_s used in all the model calculations assume that the bird is still feeding at a rate appropriate to a growth of 40g d^{-1}. It must be admitted that a bird which is panting at a rate needed to sustain an evaporative heat loss of more tha 4J s^{-1} - a water use exceeding 150g d^{-1} - will not have much time, or inclination, to feed; neither will it have much time to drink so that the higher rates of water use cannot be sustained for long periods.

The tolerance figures should be regarded as appropriate to a comparatively sudden onset of heat stress - ie the birds have not reduced their food intake in response to gradually increasing stress levels.

2. Where ventilation of the house is adequate and the birds are well separated, house temperatures of 28 to 30°C may be tolerated without stress. If the birds' effective surface area is reduced because of clustering, these threshold house temperatures fall to between 23 and 27°C with the possibility of localised stress at temperatures as low as 20°C. (see model calculations 1 and 2)

3. As hyperthermia increases and body temperatures rise, the environment temperatures may be tolerated to higher values but for much shorter periods of time. It would seem that the birds might not be able to tolerate temperatures much in excess of 30°C for more than an hour or two before some deaths occur. (see model calculation 3)

4. Allowing for the increase of house temperature over outside air temperature indicates that, with water use of 150g d^{-1}, body temperature will start to rise when outside air temperatures exceed about 25°C for a 2kg bird and 28°C for a 1.5kg bird. If effective ventilation is reduced because of clustering or any other reason, then stress may be expected to start at temperatures as low as 20°C. Deaths due to heat stress may be expected to occur when outside air temperatures exceed 30°C for well spaced birds and when temperatures rise above 20 to 25°C in cases where localised overcrowding might occur. (see model calculations 1 and 4).

Some Incidents in 1983:

To preserve anonymity, no locations are given; meteorological data are quoted for the nearest appropriate site.

1. Three sites are mentioned simply as "trouble spots" on particular dates. Maximum temperatures are given for 3 days centered on the trouble date.

Date	Maximum temperature		
	Previous day	Same day	Next day
4 July	25.1	25.4	26.6
8 July	25.4	25.5	24.7
14 July	22.6	28.9	27.7

No information on numbers dead or age of birds is available.

2. On 15 July 5,500 39-day old birds and 1,700 36-day old birds died when shed temperatures are said to have reached 93 to 94°F - about 34°C. Maximum temperatures for 13 to 17 July were:-

Date	13	14	15	16	17
T_{max}	17	25	32	20	27

This site is near the coast and was kept cool by on-shore breezes except for 15 July when a moderate off-shore breeze allowed temperatures to rise to 32°C. The suddenness of the rise in temperature may well have led to increased mortality. Since the tally of deaths attributed to a given day includes birds which died the previous evening, some of the reported deaths may have been due to the high temperatures of the 14th.

3. On one farm, over 7,000 birds were lost in 3 separate incidents.

a) On 30 July 2,700 birds at about 30 days old.
Temperatures reached 29.9, 28.3 and 28.3°C on 29, 30 and 31 July.

b) 200 43-day old birds died on 9 August.
Temperatures were 24.1, 24.7, and 22.4°C on 8, 9 and 10th.

c) 4,300 46- to 53-day old birds died on 15 August.
Temperatures for the 3 days were 28.9, 27.8 and 24.1°C.

4. During a 13-day spell, 9 to 21 July, more than 18,500 birds aged 37 to 49 died. This loss represented over 13% of stock in 4 houses.

Date	T_{max}	Number dead
8 July	27.6	-
9	27.1	828
10	26.1	380
11	30.1	204
12	30.1	14,721
13	31.2	200
14	28.1	1,133
15	29.7	359
16	30.3	112
17	25.4	194
18	25.7	305
19	25.0	82
20	21.5	53
21	24.0	66

Again, the high number attributed to 12 July are partly the result of deaths during the evening of the 11th and partly to the 12th. The tendency for fewer deaths after the 12th must be due, in part, to the steady reduction in stocking density as dead birds are removed; the initial density was 19.1 birds m^{-2} falling to 16.9 birds m^{-2} by 13th.

Climatology of heat stress

Some data are presented for Honington (between Thetford and Bury St Edmunds) as representative of much of Eastern Region, ADAS.

The number of hours when the temperature was greater than 25°C and 30°C during the 10 years 1971-80 and in 1983 are shown in Figure 1. These occasions all occur within the period May to September with the majority falling in July and August.

Risk of death probably increases with increasing length of time that the birds are exposed to high temperatures. The occurrence of spells of hourly temperatures above 25°C are shown in Figure 2. The average number of spells per year is calculated from the 10 years 1971-75, 1977-80 and 1983. While years such as 1975 and 1983 might be expected to occur in a 10-year sample, the extreme

character of 1976 should not be used to estimate an average from so short a period.

It can be seen that spells of longer than 5 hours occur, on average, less frequently than 3 times a year. However for planning purposes, it would be more prudent to allow for a year like 1983 which might occur 2 or 3 times in a 10-year period.

Conclusions

1. The simple model of heat and moisture exchange for broiler chickens here described indicated that very localised heat stress deaths might occur with air temperatures as low as 20°C and it seems probable that deaths in 6 to 8-week old birds could reach or exceed 10% when air temperatures exceed 30°C for several hours.

2. In terms of reducing heat stress, the birds' habit of sitting on the floor in groups must be viewed as counter-productive. Any measures which will cause the birds to stand up and move apart and, if possible, spread their wings to some extent, will help them to lose sensible heat more quickly.

3. The data here presented justify the criteria of 4 hours or more with air temperatures above 23°C - roughly equivalent to maximum temperature greater than 25°C - used in the Meteorological Office warning scheme offered to the broiler industry.

Agrometeorology Department
ADAS, Cambridge
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References

1. MAFF, 1976. The climatic environment of poultry houses. Bulletin 212.
2. Charles, D R and Wathes C M, 1979. Poultry environment and systems information. Environment Handout No 3
3. Sturkie P D, 1965. Avain Physiology. Bailliere, Tindall & Cassell
4. Precht H et al., 1973. Temperature and Life (page 546). Springer - Verlag
5. Charles D R, 1980. Environment for poultry. Veterinary Record, 5 April.

No of hours with temperature > 25°C

HONINGTON

FIGURE 1

Spells of N or more hours with temperature > 25°C

HONINGTON

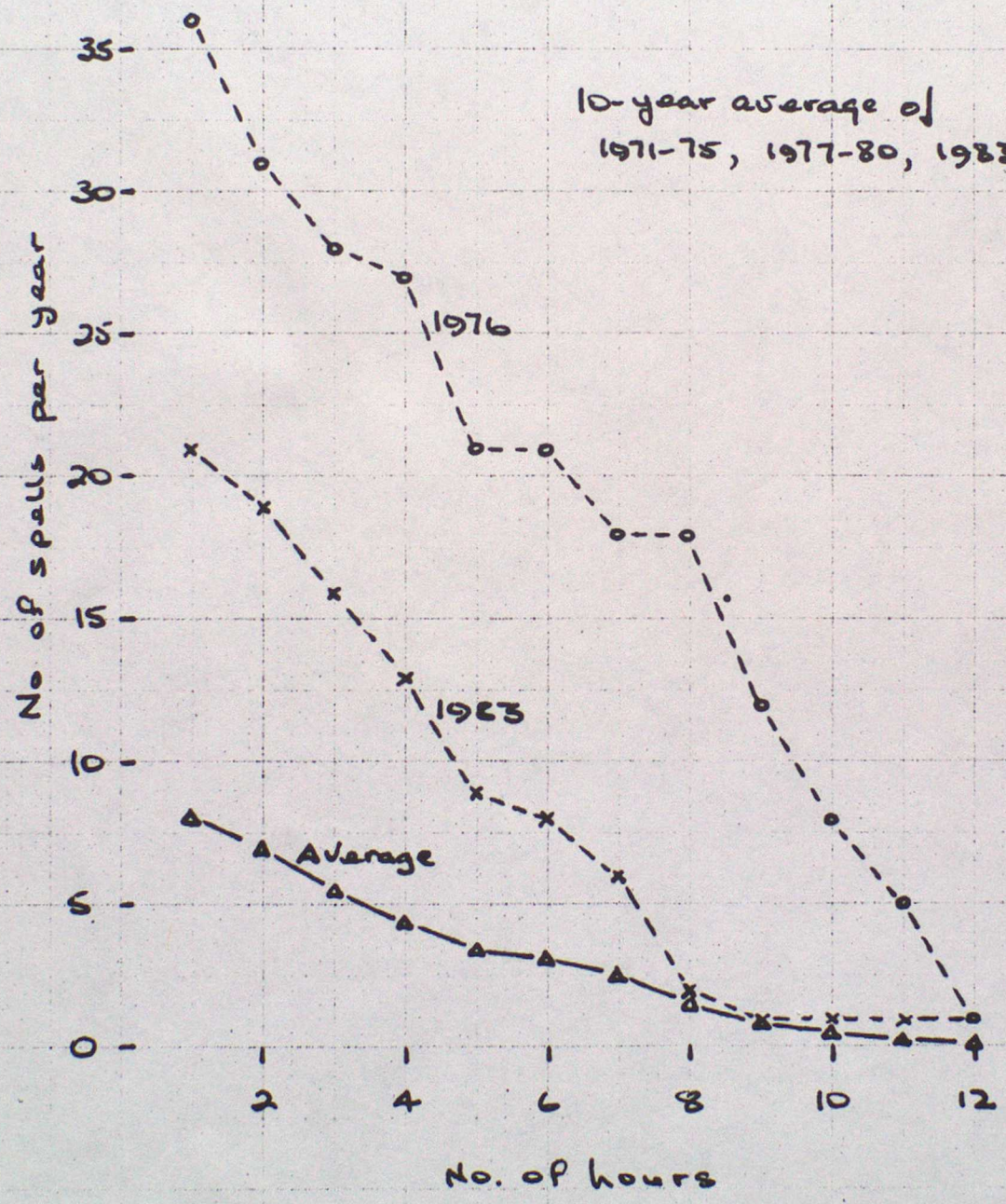

FIGURE 2